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Theoretical study of dynamic parameters of oscillating end-effectors of cleanser of a potato

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The purpose. To determine dynamic parameters of oscillating end-effectors of cleanser of potato, ensuring upgrading of cleanout of tubers from admixtures. **Methods.** Theoretical mechanics, higher mathematics and strength of materials. The program is made as well as numerical calculations on computer are carried out. **Results.** For the developed new construction of cleanser of potato of spiral type on the basis of consideration of geometry of curving of working spiral at its cross oscillations analytical dependences of change of walk of coiling of cleaning spiral as a result of its deformation, in particular simultaneous longitudinal tensioning and cross sag are gained. It has enabled to gain limitations on the maximum value of that deformation under condition of non-dropping out of tubers of potato through intra-coil space in view of constructive and kinematic parameters of cleaning spiral, its material, and technological operating conditions of separator. Execution of these conditions enables to considerably increase quality of cleanout of tubers of potato from the stuck soil and plant residues and is essential to diminish their losses. **Conclusions.** New analytical dependences are gained for determination of changed walk of arched spiral at any moment and for any intra-coil clearance during oscillating process, on the basis of which numerical calculations on the PC have been carried out. According to numerical calculations cleaning spiral at its angular velocity of twirl w = 30rad. · s–1, density of its material r = 7700 kg · m–3, elastic modulus E = 2 · 1011 Pa, radius of bar r=8,5 mm and uniformly distributed load of potato heap which intensity is equal to 1000 N · m–1, with initial walk of coiling S=48 mm at considered cross oscillations due to deformation can change a walk up to 54 mm that ensures non-dropping out of tubers of potato from cleanser.

Key words: *tuber of potato, digging up, soil admixtures, cantilever spiral, oscillations, differential equation, numerical calculations on the PC.*

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Purification of potatoes from soil impurities and plant residues after their digging is a complicated and time-consuming process, because together with the tubers on the separating tools come large and small lumps, stones, particles of haulm and rootstock, as well as soil in a state of sticky doughy mass. Separating potato tubers from so many different impurities in terms of properties and size requires cleaning tools that are perfectly adapted to the efficient sifting of impurities through the separating gaps, as well as to the simultaneous capture and forced removal of impurities.

However, the cleaning tools of modern potato harvesters are not able to provide such conditions in a relatively compact cleaner, so the existing constructions of the cleaners use a large number of different working tools, install them one after the other and thus form too long a cleaning line. This not only makes the cleaning process more complex and energy-intensive, but also contributes to a significant injury to the potato tubers.

The potato harvesters' cleaning bodies include spiral-type potato cleaners, which combine the most efficient sifting of soil impurities and plant residues through sifting gaps and effective destruction of heaps and forced capture and removal of impurities. Exactly they have large areas of separating gaps, as well as active cleaning surfaces.

Analysis of recent research and publications. Creation and research of potato heap cleaners from impurities is devoted to a considerable number of developments, as well as scientific papers, covering the results of theoretical and experimental research [1-7]. At the same time, it is either the simple separators of potato heap, or those that are built and based on the principles of ferromagnetic, acoustic, electromagnetic and other properties, or contain electronic means of separating are most carefully considered [1].

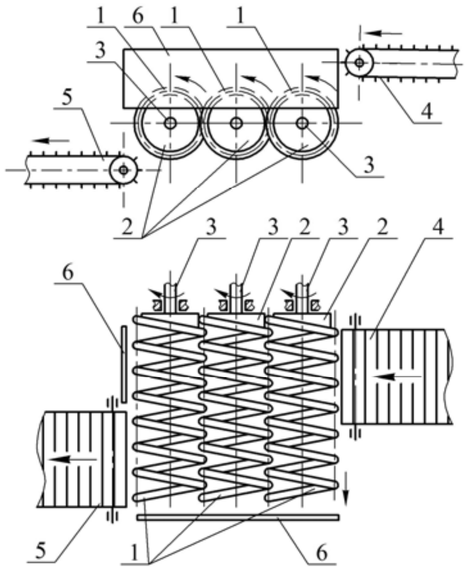
Works [9, 10, 14] are devoted to research of potato heap cleaners of spiral type. However, a small number of works, in particular [15], are devoted to the study of vibrations of working bodies of spiral separators.

Purpose of research – Determination of dynamic parameters of oscillating working elements of potato cleaner, providing improvement of quality of tubers cleaning from impurities.

Methods of research. The researches were carried out with the use of methods of theoretical mechanics, higher mathematics and resistance of materials, as well as methods of programming and numerical calculations on the PC.

Research results. We have developed an advanced spiral type potato cleaner, the construction of which is confirmed by a patent of Ukraine [8]. The experimental sample of the specified cleaner was made, the general view and the constructive scheme of which are presented on Fig. 1.

а



б

Fig. 1. Spiral type potato cleaner:
a – general view; б – structural scheme (side and top view):
1 – cantilever cleaning spirals; 2 – the hub; 3 – drive shafts;
4 – feed conveyor; 5 – unloading conveyor;
6 – protective screens

The spiral potato peeler consists of three spiral 1 spirals in series, which form an equal peeling surface on top. The spirals 1 are mounted on the console in such a way that one end of the spirals is fixed on the hubs 2, connected to the drive shafts 3, and the other ends of the spirals are located freely. The spirals 1 are overlapped and the drive shafts 3 ensure that they rotate at the same angular velocities in the same direction. The infeed conveyor 4 is connected to one side of the cleaning surface formed by spirals 1, and discharge conveyor 5 is located on the opposite side. The sides around the cleaning cantilever spirals 1 are covered by protective screens 6.

The spiral type potato cleaner works as follows. Conveyor 4 continuously feeds the potato layer dug out of the ground to the cleaning surface formed by three cantilever spirals 1. As a result of falling from a small height, the soil cavity with potato tubers is partially destroyed and dispersed into individual components, first on the nearest helix 1, and then passed on to other spirals 1. As spirals 1 from a hub 2 are connected with drive shafts 3, carrying out rotary movements, spirals 1 take over the tubers of potatoes and lumps of soil by the turns of a body and begin their transportation both in an axial direction, and in radial. However, thanks to the considerable lumen (between the turns of each spiral 1 and the space between the spirals 1), small soil particles are immediately sifted downwards outside the cleaner in large quantities.

The main advantage of such a construction of a spiral type potato cleaner is that in the process of its operation, the cleaning tools - spirals, mounted on a console, carry out under the influence of variable load, forced oscillations. These oscillations cause periodic deformation of spirals, which contribute not only to changes in their pitch values (i.e. the distance between adjacent coils), which leads to an increase in sifting gaps, but also transverse bends in the downwards direction and longitudinal strains that contribute to the intensification of potato tubers' movements on the cleaning surface under the influence of gravity. Constant periodic changes in the spiral pitch thus create the conditions for the forced capture of soil impurities and crop residues from above the cleaning surface and their transport downstream of the cleaner. Also there is an effective self-cleaning of spirals, as a whole raises quality of clearing of potatoes tubers from impurity. Transverse bends of spirals, with simultaneous rotary motion, change the horizontal position of the cleaning surface, which also contributes to the effective cleaning of potato tubers from sticky soil.

To determine the dynamic parameters of the oscillatory process, which occurs when cleaning potato tubers from impurities, i.e. forced vibrations of cantilever spirals, it is necessary to construct an equivalent scheme. Fig. 2 shows the equivalent scheme of vibration of a unit spiral mounted on the drive shaft, which provides it with rotational motion. The spiral radius *R* is shown in two positions: horizontal (i.e. undeformed) and deflected downwards under the action of a variable load (a pile of potato heap per spiral), which are approximated by the distributed load with intensity $\tilde{q}(z,t)$.

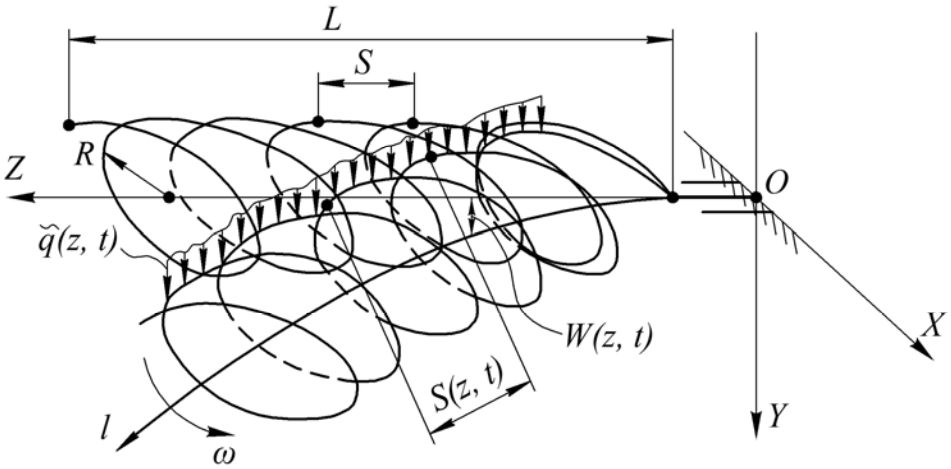


Fig. 2. Equivalent scheme of spiral spring oscillation under the influence of external variable load from the side of the potato heap

We will choose the spatial Cartesian coordinate system $OXYZ$, which center O located on the axis of the drive shaft of the spiral, the axis OZ passes through the longitudinal axis of the spiral is in an undeformed state, the axis OY pointing down and the axis OX is located perpendicular to the plane OYZ. In a deformed state, that is, in a curved position, the axis of the spiral itself is indicated by Ol. The length of the spiral in the deformed state is indicated by L. We denote the spiral pitch in an undeformed state due to S, and through $S(z,t)$ – the spiral pitch that became in the event of a deformation of the spiral. The pitch $S(z,t)$ is variable in current length z spiral as well as time t. The spiral deflection marked on the equivalent scheme is $W(z,t)$ also has a functional dependence on the current length z spiral and time t. The direction of rotation of the spiral with angular velocity ω shown by an arrow.

On the basis of the made equivalent scheme we will execute theoretical researches of dynamic parameters of the given oscillatory process. An important characteristic of the elastic cantilever ("spiral") is its reduced axial moment of inertia of the section I_R, which will be a size of a variable on length of a spiral as depends on the angular parameter ψ, which determines the current length of the spiral along its longitudinal axis z. You can use the following expression to find it [15]:

$$I_R = \frac{\pi r^4}{4}\left[\frac{\sin\gamma}{1+(1+2\nu)\sin^2\psi\cos^2\gamma}\right], \qquad (1)$$

where r – spiral winding rod radius; ν – Poisson's ratio of the material from which the spiral is made; γ – screw line lift angle.

If the angular parameter of a spiral is presented by the following expression:

$$\psi = \psi_o + \omega t = \frac{2\pi \cdot z}{S} + \omega t, \qquad (2)$$

where ω – angular velocity of rotational motion of a spiral,

then we get the dependence of the given moment of inertia of the section I_R spiral console length (coordinates z) and time t, at constant winding pitch $S = \text{const}$ and angular velocity $\omega = \text{const}$, that is

$$I_R = \frac{\pi \cdot r^4}{4}\left[\frac{\sin\gamma}{1+(1+2\nu)\sin^2\left(\frac{2\pi \cdot z}{S} + \omega t\right)\cos^2\gamma}\right]. \qquad (3)$$

Having carried out numerical calculations on the PC on expression (3), we receive graphic dependences of the reduced moment of inertia of section I_R spirals from its longitudinal coordinate z (fig. 3).

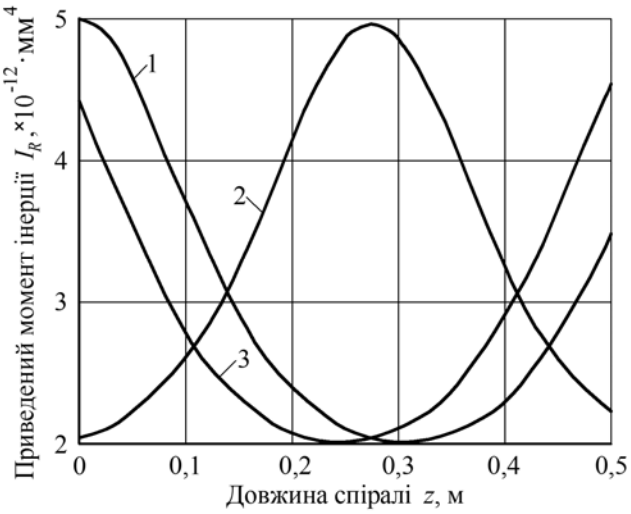


Fig. 3. Change on the length of the helical moment of inertia I_R section of a console with a spring diameter d = 17 mm, winding pitch S = 48 mm, upward winding angle γ = 7° and the angular velocity of rotation ω = 30 rad.·s^{-1} in moments of time: 1 – t = 0 s; 2 – t = 1 s; 3 – t = 2 s

To determine the step change S of winding in the process of spiral deformation at its vibrations, first let us consider the geometry of the spiral bending. For this purpose, let us construct the calculation scheme of the helix axis bending (Fig. 4). We consider that the bending of the helix can occur conditionally by an arc of corresponding curvature.

To describe the longitudinal and transverse deformation of the spiral, we introduce a plane Cartesian coordinate system *OZY*, the beginning of which (point O) is at the point of attachment of the cantilever spiral, the axis OZ directed horizontally to the right, the axis *OY* pointing downwards. In this case, we assume that the longitudinal axis of the undeformed (unfolded) spiral is located along the axis OZ, and the longitudinal axis of the curved spiral is along the curve Ol. To study the longitudinal (tensile) and transverse (bending) deformations of the spiral axis, we consider two arbitrary adjacent turns of the unfolded spiral. Let the left turn be numbered *i*, right turn - under number $i+1$, the center of the *i* turn will be the point A_O, the center of the $i+1$ turn – point B_O, which are located on the axis OZ and have coordinates $A_O(z_i;\ 0)$ and $B_O(z_{i+1};\ 0)$ in accordance. Obviously, the distance between the points A_O and B_O will be equal to $A_OB_O = z_{i+1} - z_i = S$, where S – the step of winding a non-curved spiral, S = const.

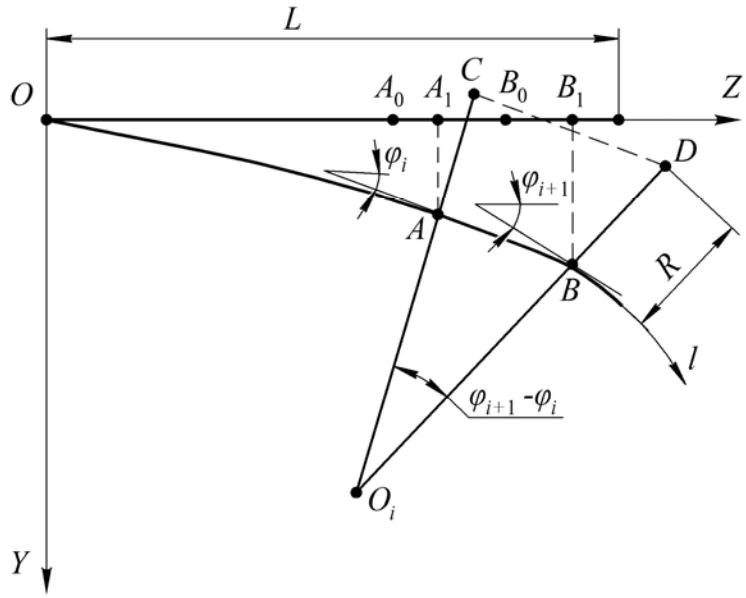


Fig. 4. Calculation scheme of cantilever elastic spiral bending

Let us consider the longitudinal and transverse deformation of the spiral. At longitudinal deformation of a spiral a point A_O will move along the axis OZ at some point A_1, point B_O – at some point B_1 with coordinates $A_1(z_i + \Delta_i;\ 0)$ and $B_1(z_{i+1} + \Delta_{i+1};\ 0)$ in accordance, where Δ_i and Δ_{i+1} – point movements A_O and B_O respectively, due to the longitudinal deformation of the spiral. When the spiral is deformed transversely, the point A_1 by deflection will move to a point *A*, point B_1 – in point *B*. These points are located on the curved axis Ol, and the point A_1 will move along the axis *OY* by the amount of deflection W_A, point B_1 – by the amount of deflection W_B.

So, points *A* and *B* will be centers of turns with numbers *i* and $i+1$ respectively, after longitudinal and transverse deformation simultaneously, and, accordingly, their coordinates will be $A(z_i + \Delta_i;\ W_A)$ and $B(z_{i+1} + \Delta_{i+1};\ W_B)$.

The distance between the points *A* and *B* will be defined as follows:

$$AB=\sqrt{(Y_B-Y_A)^2+(Z_B-Z_A)^2}=\sqrt{(W_B-W_A)^2+(S+\Delta_{i+1}-\Delta_i)^2}. \quad (4)$$

A curve that passes through a point *A* and *B*, describes the deflection of the longitudinal axis of the spiral. We will draw a tangent to the curve in these points, then the angle between the tangent and the horizontal will φ_i and φ_{i+1} respectively, which determines the angle of rotation of the section relative to the initial position. The rotation angle of the section is determined from the following expressions [22]:

$$\varphi_i=\arctan\frac{dW}{dz} \quad \text{while } z=Z_A; \qquad \varphi_{i+1}=\arctan\frac{dW}{dz} \quad \text{while } z=Z_B. \quad (5)$$

Suppose that the normals that are drawn through the points *A* and *B*, intersect at a point O_i, then the distances from this point to the points *A* and *B* – is the radius of curvature of the curve AB in points *A* and *B* in accordance.

Let us denote $O_iA=\rho_i$, $O_iB=\rho_{i+1}$. Then, according to [22], we will get:

$$\rho_i=\frac{1}{\dfrac{d^2W}{dz^2}} \quad \text{while } z=Z_A, \qquad \rho_{i+1}=\frac{1}{\dfrac{d^2W}{dz^2}} \quad \text{while } z=Z_B. \quad (6)$$

As you can see from the fig. 4, the angle between the specified radii of curvature is $\varphi_{i+1}-\varphi_i$.

If we will continue the normal O_iA and O_iB by the size of the spiral radius $R=AC=BD$, we will get the end (upper) points *C* and *D* of the deformed *i* and $i+1$ the turns of the working (separating) surface, respectively, on which the process mass is located. From the figure. 4 it is visible that the coordinates of the points *C* and *D* in the received coordinate system are equal:

$$Y_D=W_B-R\cos\varphi_{i+1}, \qquad Y_C=W_A-R\cos\varphi_i,$$
$$Z_D=Z_B+R\sin\varphi_{i+1}, \qquad Z_C=Z_A+R\sin\varphi_i. \quad (7)$$

The distance between the points *C* and *D* determines the distance between adjacent turns, that is, the pitch between turns in the upper part of the coil after deformation of the spring.

Then the mentioned pitch will be equal:

$$CD=\sqrt{(Y_D-Y_C)^2+(Z_D-Z_C)^2}, \quad (8)$$

or, given the expression (7), we will get:

$$CD=\sqrt{\left[W_B-W_A-R(\cos\varphi_{i+1}-\cos\varphi_i)\right]^2+\left[S+\Delta_{i+1}-\Delta_i+R(\sin\varphi_{i+1}-\sin\varphi_i)\right]^2}. \quad (9)$$

We will set the condition of the permissible value of the winding pitch to not fall out of the potato tubers into the interturn lumen. Therefore, it is necessary that $CD\le[S_{\max}]$, where $[S_{\max}]$ – the maximum permissible value of the winding pitch after deformation, determined by the geometric parameters of potato tubers.

Taking into account the specified inequality and expression (9), we obtain the condition that potato tubers do not fall out into the interturn lumen taking into account the construction and kinematic parameters of the cleaning spiral, the material from which it is made, and the technological modes of operation of the potato peeler cleaner.

Using the cosine theorem from the triangle O_iCD (fig. 4), write down the equivalent expression that defines the pitch of a spiral at its bending deformation with simultaneous stretching, and, taking into account the specified roughness, we obtain the equivalent condition of not falling out of potato tubers into the interturn lumen:

$$CD = \sqrt{(\rho_i + R)^2 + (\rho_{i+1} + R)^2 - 2(\rho_i + R)(\rho_{i+1} + R)\cos(\varphi_{i+1} - \varphi_i)} \leq [S_{\max}]. \quad (10)$$

Thus, the received analytical dependences allow to model dynamics of a console working element (cleaning spiral) at performance of technological process at the chosen constructional parameters and operating modes, proceeding from conditions of not falling out of potato tubers from a separating surface at variable loading and taking into account change of the moment of inertia of an elastic console in time and on length.

CONCLUSIONS

On the basis of consideration of the bending geometry of the working spiral of the potato peeler at its transverse oscillations the analytical dependences for determination of the variable pitch of the bent spiral at any moment of time and for any interturnal lumen during the given oscillatory process are received.

The obtained analytical expressions of restriction on maximum change of cleaning spiral pitch at its oscillations from the condition that potato tubers do not fall into the interturn space of the spiral taking into account construction and kinematic parameters of the cleaning spiral, the material from which it is made, technological modes of operation and the size of tubers.

As the numerical calculations on the PC show, a cleaning spiral with the above parameters with an initial winding step S = 48 mm at considered transverse oscillations due to deformation can change the pitch up to 54 mm (without taking into account the thickness of the bar from which the spiral is made), which will ensure that the potato tubers do not fall outside the cleaner.

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